U.Porto Journal of Engineering, 8:6 (2022) 76-89
ISSN 2183-6493
DOI: 10.24840/2183-6493_008.006_0006

Received: 28 February, 2022
Accepted: 7 July, 2022
Published: 28 November, 2022

Characterizing Academic Engineering Research Groups: A Case Study of the Advanced Joining Processes Unit

Eduardo A. S. Marques[1], Ricardo J. C. Carbas[2], Lucas F. M. da Silva[3]
[1]INEGI - Institute of Science and Innovation in Mechanical and Industrial Engineering, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (emarques@fe.up.pt) ORCID 0000-0002-2750-8184;
[2]INEGI - Institute of Science and Innovation in Mechanical and Industrial Engineering, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (carbas@fe.up.pt) ORCID 0000-0002-1933-0865;
[3]Department of Mechanical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (lucas@fe.up.pt) ORCID 0000-0003-3272-4591

Abstract
Academic research is a key activity of higher learning institutions, where the knowledge, skills and capabilities of the staff are directed towards scientific activities. The case of academic engineering research groups is quite particular, as they must perform academic research work but still consistently work with industrial partners in problem-solving research activities. Although they appear to be distinct, these aspects are interconnected and combining impactful research work and academic training is highly advantageous to group performance. This paper studies the operation of academic engineering research groups, starting with a literature review on the subject, followed by an analysis of a case study. The target of the case study is the Advanced Joining Processes Unit, part of the Institute of Science and Innovation in Mechanical and Industrial Engineering and the Faculty of Engineering of the University of Porto, a leading research unit in mechanical engineering, performing research on advanced joining processes. The main lesson drawn is that to achieve lasting success and significant impact on the scientific community and society, a research group must operate with clear and result-oriented leadership, able to provide a work environment with well-defined goals, and which is consistently working towards knowledge generation and dissemination.

Author Keywords. Research Approaches. Mechanical Engineering. Dissemination.

Type: Research Article

1. Introduction

Scientific research is a key activity of higher learning institutions, irrespectively of their field of actuation. In the first half of the 20th century, the Austrian-British philosopher and academic Karl Popper (2014) postulated that a scientist should not only employ simple observation and inductivism to seek validation for its hypotheses in datasets but should instead actively design experiments and activities that strongly attempt to disprove them. Thus, he became the first to define the scope of work of a scientific research group: seeking the truth, even if the conclusions are the complete opposite of that of the initial assumption. In the case of the engineering research groups, the research effort also includes the adaptation of these scientific methodologies to produce a physical, material result, exploring how existing scientific knowledge can be used to directly create novel materials, objects and even methodologies. The first clear separation between basic and applied research was made by the Organisation for Economic Co-operation and Development (OECD) in 1966 (de la Mothe 1992). Basic research is given as "the systematic pursuit of new scientific knowledge without the aim of specific practical application", while applied research as "the pursuit of knowledge with the aim of obtaining a specific goal".

Thus, almost the entirety of the work being carried out in technological development activities is quite far from basic, fundamental research. An often-cited study in this regard is Project Hindsight, a post-World War II study on weapon development projects (Sherwin and Isenson 1967). Among all the development activities studied, the vast majority were found to be of technological or applied nature, and only 0.3% were classifiable as basic, undirected science.

Eekels and Roozenburg (1991) compared the structures of scientific research and those of engineering design activities, concluding that these two aspects are distinct but not independent, being strongly interwoven together.

This paper aims to highlight the specificities of the modern research groups which operate in the technological oriented, engineering field and explain how they can evolve and become geared towards clear and well-defined objectives, conciliating robust academic activity with actions that are oriented toward solving real-world engineering problems.

The methodology used in this paper employs a study of the existent literature dedicated to analysing the operation of engineering research and research groups in general. Here, the characteristics of these research groups and the relative impact they have on the performance and effectiveness of the group are thoroughly discussed.

The lessons drawn from the literature review are complemented with the analysis of a case study. This case study describes in detail the operation of the Advanced Joining Processes Unit (AJPU), part of the Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI) and the Faculty of Engineering of the University of Porto (FEUP). With this case study, the authors wish to highlight how these operational aspects are interconnected and how the different activities of an academic engineering research group serve to support the knowledge generation process and have a meaningful impact on the industrial sector.

2. Study of the Literature

2.1. The modern scientific research group

Scientific research plays a vital role in the advancement of modern society, providing novel tools for solving major problems in almost any field of knowledge. However, while in the not-so-distant past, scientific ground-breaking research could have been carried out by an individual working alone, modern scientific research has exponentially grown in complexity and is now a much more social affair. Perhaps the most powerful illustration of this effect is the fact that it is nowadays very rare to find scientific papers with a single author. Most research results from cooperation between scientists, who participate in a wide range of social scientific activities. For example, in its book on the philosophical and social aspects of science and technology, Ziman (1987) described the scientific education processes, the publication of scientific papers, debates, award prizes and conferences as major examples of this cooperation. But perhaps the most important of these socialization activities is the establishment of research groups. These groups are structured collections of highly qualified individuals who assemble their expertise and skills to cooperate and work towards a common scientific goal. Accordingly, modern science has a great social component associated with it and if one wishes to generate high-quality scientific data, it will undoubtedly benefit from operating within a solid and effective structure, which can provide both the necessary technological resources and a stable and nurturing work environment.

However, successful research work cannot only be measured by working towards new scientific achievements since science is always associated with education activities. New scientists are trained by successfully completing challenging postgraduate programs, where knowledge passed on by the supervisors is used as a stepping stone for further developments by the candidate.

2.2. The research group environment and leadership

The success of a research group is ultimately deeply linked to its ability to provide an optimal work environment for all its members. The classic work of Hackman and Walton (1986) on functional leadership theory suggests that effective leadership is perhaps the most critical factor in ensuring success in a workgroup, something which still rings true for scientific research groups. But effective leadership cannot be just achieved with the direct and immediate actions of the leader. It must instil a set of group behaviours that always ensures that the objectives of the group are achieved. In another important work, Bland and Ruffin (1992) conducted a major review on the key factors or characteristics essential to establishing a successful research group, identifying twelve different factors. These are: (1) clear goals that allow research to be coordinated in a common direction, (2) placing emphasis on research work, (3) creating a clear and distinctive culture, (4) and a positive group climate, (5) ensuring that leadership is always participative and assertive, (6) creating a decentralized organization that does not require full approval through the chain of command for every single activity, (7) frequent communication between all members of the research group to ensure maximum cooperation and learning, (8) making sure that resources are easily accessible, including human resources, (9) creating a diverse research group, with different backgrounds and experiences, (10) setting appropriate rewards to ensure motivation, (11) placing special care in the recruitment process, and, lastly, (12) implement a leadership structure with expertise in research and in creating a solid organizational structure. Leadership is thus encouraged to be highly proactive. The work of Isaacson (2012) analyses a famous example of highly proactive leadership by dissecting the unique approach to management of Steve Jobs. This work described how his leadership style for research and development activities was guided by a laser focus on objectives, an incessant search for simplification, almost at any cost and a strong sense of personal responsibility. The work of Heinze et al. (2009) corroborates many of these recommendations, where it is shown that optimal creative accomplishments are often associated with organizational contexts with sufficient access to a complementary variety of technical skills, stable research financing, immediate access to resources, and knowledge existent outside the group, and a leadership structure that facilitates research.

Braun et al. (2016) further stated that in academia, both individuals and research groups seek innovation through relatively free knowledge creation and transfer processes but are often beset with a struggle between freedom to create and strict procedures, regulations and performance evaluation criteria, which a leader must understand and navigate by communicating compelling visions, sharing responsibilities, and managing complexity in order to be effective.

Hansson and Mønsted (2008) state that adopting an entrepreneurial strategy is actually more important than traditional management to create new and effective research structures. Evans (2012) urges the research leaders to recognize the width, multidimensionality and complexity of the researcher development process beyond the more easily observable behaviour, such as productivity and output. Changing viewpoints, mindsets and perceptions and increasing intellectual capacity are all elements to be closely monitored.

2.3. Student engagement

Feldman, Divoll, and Rogan-Klyve (2013) noted that the engagement of students in a given research field increases slowly as their own intellectual proficiency is increased, as the learning process can only occur via direct action, growing in effectiveness if the student can participate freely in the activities of the research group. However, the student must be guided by direct and consistent feedback from the supervisors. An important addendum to this process is given by the work of Schmoch and Schubert (2008), which states that these activities, such as the publication of papers and participation in conferences, should be oriented not toward their quantity but toward the impact they have on the field.

Furthermore, undergraduate students often see experience in engineering research groups as a very effective method to improve their competencies and even increase their attractiveness to potential employers. Zidney et al. (2002) interviewed alumni who rated their experience as "very" or "extremely important" and highlighted the fact that it brought long-lasting benefits. Most declared this experience to be a key factor behind their ingress in postgraduate studies and one which led to improvement of their personal, scientific and social skills. These conclusions were also supported by the work of Narayanan (1999), which states that the research groups should expose undergraduate students to research as much as possible. Importantly, Narayanan (1999) strongly recommends that these undergraduate students should operate under well-defined goals and always under the close supervision of a senior graduate student. It is also proposed that the quality of the undergraduate research should be maintained by requiring the publication of the results, either as a paper or as participation in a major technological conference.

2.4. Knowledge transfer

The classical avenues of knowledge transfer in most scientific fields are comprised of the publication of documents and participation in scientific meetings. However, Latour (1987) warns that while these are positive for the development and networking of an academic researcher, they do not exactly serve the aims of a group operating in applied technological research. In such cases, the knowledge generated tends to stay within the boundaries of a given scientific community and although we will later see that firms are increasingly more attentive to the content and scope of these publications, the transfer of knowledge to the industrial sector is quite limited. In addition, Top and Broekstra (2008) state that even if firms do absorb the knowledge brought forward in these manuscripts and conferences, there is an important loss of many intermediate results and techniques that are of utmost importance for those who might be tasked to implement a novel technology in an industrial setting.

It is also important to consider what advantages can academia and the industry draw from cooperation. The work of Bercovitz and Feldmann (2006) establishes that this knowledge transfer is, in fact, a major driver of innovation and economic growth. A major reason behind this has been identified by Plerou et al. (1999), finding that the growth dynamics of the university research activities and business firms do indeed have important similarities, a result of the combined effect of peer review activities and government direction (for academia) and market forces such as consumer requests and product regulation (for the industry). Interestingly, the work of Feller, Ailes, and Roessner (2002) suggests that the firms that establish cooperation with academic research units are not searching for ready-made products or processes but are instead seeking to understand new knowledge modes and knowledge acquisition methods that they themselves do not master, the so-called "upstream modes of knowledge".

Knowledge generated in technological academic settings is often an economical proposition for industrial entities, as it matches their most crucial needs and allows them to become more competitive without requiring the establishment of novel and complex internal research and development processes. But of course, not only the industries benefit from this relationship. As D'Este and Perkmann (2011) note, researchers can draw from this cooperation to obtain additional funding but, perhaps most importantly, can use this connection to identify new research directions which might not be evident when looking at the issue from a purely academic standpoint.

The extensive literature review carried out by de Wit-de Vries et al. (2019) calls to the stark difference in goals resulting from different institutional cultures, which often create ambiguity, problems with knowledge absorption and disagreements on how this knowledge can be applied in practice. However, this can be mitigated by gradually creating trust and ensuring a consistent level of communication. For instance, it is preferable to initiate cooperation with a more reduced, low-risk approach, use it to develop a shared work methodology and then scale the project to solve larger and more challenging problems. Furthermore, Melin (2000) notes that all successful collaborations are characterized by strong pragmatism and a high degree of self-organization in the academic research group. Finally, it also stated that the organization must allow researchers to establish joint ventures and fund projects on a team or network basis. As a final note, it is important to highlight the work of Mirowski and Van Horn (2005), which warns of the dangers that a research group faces when it becomes almost entirely supported by the industrial sector. They describe how such dependency has given rise to contract research organizations (CROs), entities that are highly susceptible to evolve towards a purely commercial approach to scientific research. In this case, the original mission and freedom of a technological research group are all but lost in return for greater economic stability.

2.5. Summary of review

In sum, a research group must be able to create an adequate research environment, providing the necessary conditions for training new members and to understand how industrial cooperation activities stimulate technology transfer and improve the group. A successful research group acting in a technological setting must follow a circular operational process in which knowledge is generated, disseminated to the scientific community, and transferred to the industry. In this cycle, industrial challenges are used to inspire the generation of additional knowledge, which further drives this circular process (Figure 1).

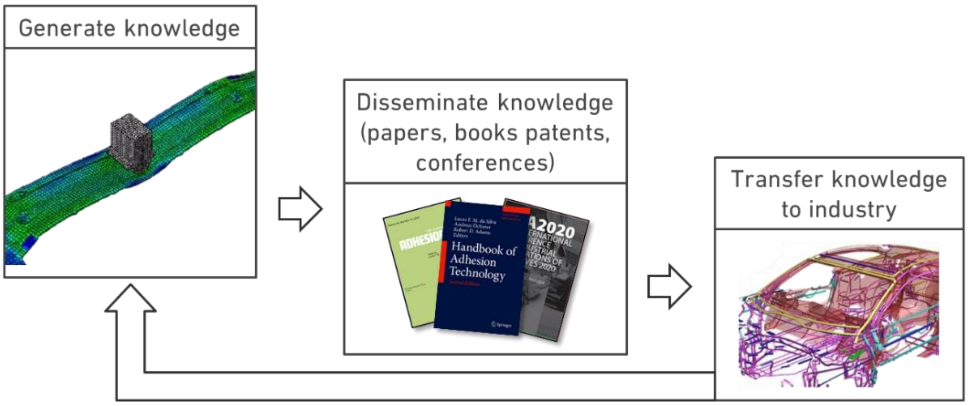

Figure 1: The circular process of operation of a technological research group

This single knowledge cycle has some similarities to what is described by Top and Broekstra (2008), which divides the research activities into two knowledge creation cycles. One leads to purely scientific insight, and the other feeds upon this pure scientific research to drive industrial innovation.

3. Case Study

As stated previously, the subject of this case study is the AJPU, which operates within FEUP (an engineering school) and INEGI (a university-industry interface institute) and performs research on advanced mechanical joining processes, with an emphasis on adhesive bonding, plastic forming and welding joining techniques. In full agreement with the seminal work of Bland and Ruffin (1992), this unit follows a highly result-oriented operation dedicated to technological research with a high level of knowledge transfer.

The AJPU operates with the previously introduced, three-step, sequential research approach. The first step is, of course, knowledge generation. In this specific case, dissecting an engineering research group, this is not necessarily achieved with basic, fundamental research but is instead more oriented toward creating novel material testing procedures and developing numerical and analytical models that can reproduce complex material behaviour. The intermediate step is the dissemination of that knowledge to the scientific community, which is mostly done with participation in conferences and the preparation of specialized literature. The last step corresponds to a direct transfer of the knowledge being generated, where it is passed on to the industrial sector, which will use in its products. New challenges and issues identified in this last step are then used as a basis for new knowledge generation activities, closing the loop.

3.1. The knowledge generation process within the AJPU

3.1.1.Major research activities and funding sources

The research process cycle employed in the AJPU always includes direct feedback from industrial partners. Thus, although the most ground-breaking research and development work carried out in the group is driven by the ideas and inspirations of the group researchers, it is always guided by the need to solve practical problems and challenges. In fact, as described by several authors (Bercovitz and Feldman 2006; Plerou et al. 1999), it is not unusual to find that both the academic and industrial research trends are sometimes convergent, even if the preferred approaches and priorities might differ somewhat.

The research carried out in this initial phase is usually of a less applied nature and this means that even if the research work produces acceptable results, it will still be at a stage that is quite far from practical implementation or will at least provide solutions that are not quite oriented towards a specific practical application. If we describe this using the Technology Readiness Level (TRL) standardization, the technology at this initial phase will at best correspond to a TRL of 4, which means a technology that is shown to work in a laboratorial setting, but still has a long path to traverse towards practical implementation. An example of a typical research process is shown in Figure 2, where a joint design process is gradually studied. This research process then evolves to become closer and closer to practical application and this will lead to a near-production ready geometry that should be experimentally validated and then implemented in practice (TRL of 7 or 8).

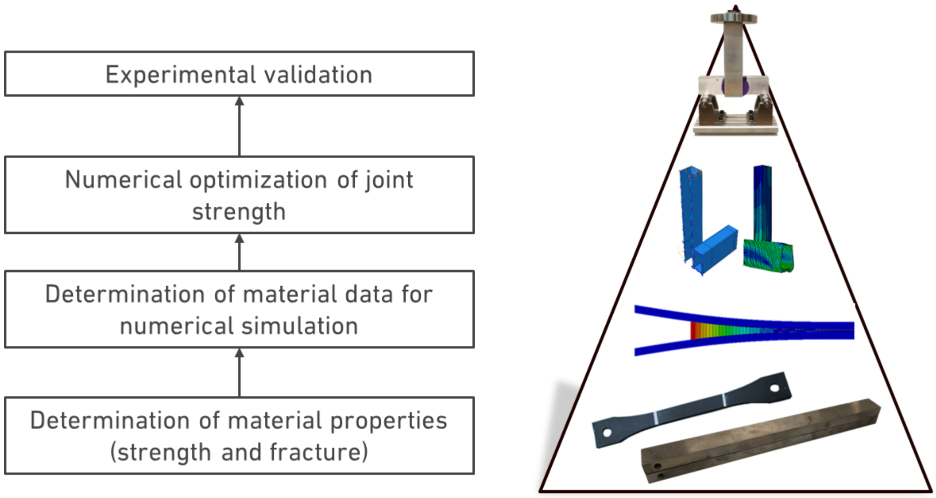

Figure 2: The research procedure

The initial phase of these research works is riskier and requires extensive experimentation and testing of new concepts, often without any assurance of success. Thus, it is challenging to obtain industrial funding at this stage and support can only be obtained via financed research projects and individual research grants, both for Ph.D. candidates and post-doctoral researchers. The funding entities that support these projects and grants are varied, and in the case of the AJPU, include the Portuguese Foundation for Science and Technology (FCT) and the European Union.

The AJPU is deeply interconnected with the Department of Mechanical Engineering of FEUP, and thus it is logical that any research work should be conducted in parallel with an academic qualification in this field, such as MSc or a Ph.D. degree. These financed projects and grants usually are oriented to support this personnel qualification process. Note that while industrial users are often not directly responsible for providing funding to these projects, they can still be associated with them by helping define the major research subjects that can eventually lead to knowledge with important industrial applications in the medium to long term future.

A growing number of industrial partners are choosing to directly sponsor MSc and Ph.D. programmes in the field of structural joining, but at this stage, this activity is mostly supported by government funding. Nonetheless, the current outlook is that the generation of the fundamental knowledge process is always kickstarted, even if indirectly, by the needs of industrial users and supported by governmental funding. The creation of sound and innovative research proposals for these financing institutions is thus a critical activity of research groups, as it creates the necessary conditions to develop the initial research that will support subsequent group activities. In the AJPU, all the post-doctoral researchers are highly encouraged to prepare and submit as many projects as possible to these calls and all members participate in the analysis and review of the proposal, to ensure its feasibility, logical organization and clarity, leading to success rates that have risen as high as 75% in some calls.

3.1.2. Group leadership and structure

As shown in the literature, the most important asset of a research group is the availability, motivation and skills of the researchers that composite it. Management of these human resources is critical, as the AJPU has grown into a relatively large research group and can operate under maximum efficiency with the establishment of a set of guidelines. A well-defined structure is implemented in this research unit to ensure a smooth operation. The group is led by a full professor, supported by two other professors (experts in automation and machine design) and includes post-doctoral researchers with different expertise fields that guide the postgraduate and undergraduate students in their research. At the time of writing, the AJPU is composed of around 40 members. In addition to the professors, the unit includes six post-doctoral researchers and eighteen Ph.D. candidates who are performing their research within this unit. The number of MSc candidates that join per year is variable, averaging around nine.

The organization is managed mainly by the establishment of well-defined individual and collective objectives, which are well understood by all team members and serve to drive the cooperative workflow. This motivates the group and provides a collective sense of purpose. In addition, there is an effort to establish a well-defined style and culture of the group, which can be defined as maximizing the efforts of the group towards realistic and impacting objectives. For example, there are no strict requirements for work schedules and members are free to schedule their work as they wish as long as they can meet all of the agreed-upon objectives. Figure 3 provides an organizational diagram for the research unit, showing how the different levels are all interconnected and decentralized.

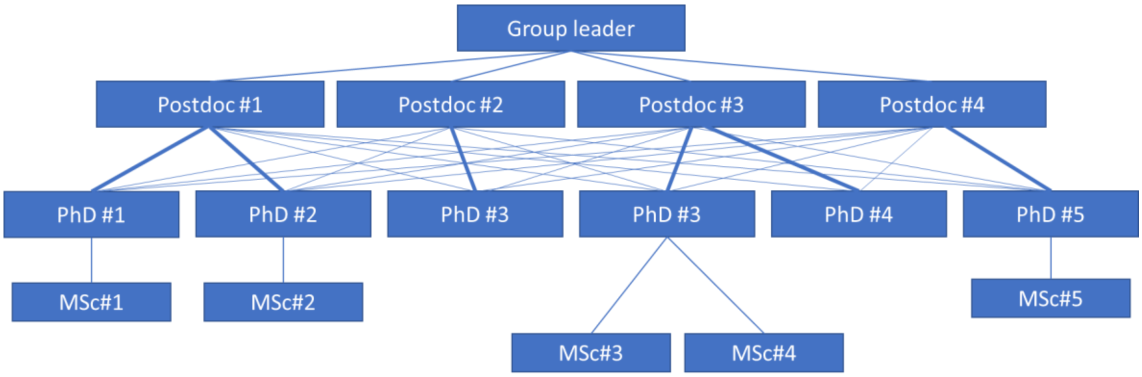

Figure 3: Organizational diagram of the AJPU

An additional degree of cooperation and teamwork is provided by the establishment of frequent and effective communication paths. Regular team meetings play a key role, serving as a forum where the group members are highly encouraged to show their work and describe current challenges, concerns and prospects for the future. This ensures that the unit competencies can be fully leveraged to solve problems and avoid the repetition of previous mistakes. Meetings also allow the leadership to provide feedback to the group on overall progress and seek feedback and input from the group.

3.2. Knowledge dissemination activities

3.2.1.Academic dissemination activities

One of the main knowledge dissemination avenues in the AJPU is an academic qualification, that is, educating individuals in science and engineering research, mainly achieved as part of MSc and Ph.D. programmes. This is possible because this unit is closely interlinked with the Department of Mechanical Engineering of FEUP and its members serve as supervisors and co-supervisors of theses.

3.2.2.MSc and Ph.D. theses

MSc theses mostly start as a set of proposals presented to students who are entering the final year of their Master's in Mechanical Engineering at FEUP. The AJPU mainly proposes research theses in the field of design of mechanical structures, automation and materials and processes. Candidates are free to select and apply for these proposals, but the proposals available usually outnumber the candidates, which creates a healthy environment of competition.

MSc theses are then carried out under the close guidance of Ph.D. candidates who, crucially, are important stakeholders in these works, as the MSc theses they supervise will play an integral role in overarching Ph.D. theses. In line with the suggestions of Narayanan (1999), this supervision is accompanied by clear goals, such as the preparation of a scientific research paper or participation in a scientific conference. By understanding the importance of their work, candidates gain additional motivation to successfully conclude their thesis and are ultimately able to graduate with skills that are highly sought after by employers.

The operation of Ph.D. theses is distinct from that of the MSc thesis, as these are longer, more involved research efforts. Candidates arrive via a set of different paths, but most are MSc graduates that have expressed their intention to proceed toward a Ph.D. and are integrated into a research project which is already fully planned by the research group. In other cases, Ph.D. candidates can arrive from an industrial setting, bringing their own research objectives and forming a partnership between a company and the AJPU. It is also very common to welcome candidates who arrive from foreign higher learning institutions from all over the world, seeking the unique expertise of the AJPU to improve the quality of research work.

A given post-doctoral researcher will be the titular supervisor and have the main responsibility in guiding the Ph.D. candidate, but all other post-doctoral researchers are genuinely committed to aiding the supervising process. Consistent publication and dissemination are achieved by structuring Ph.D. theses as a set of interrelated but distinct scientific papers in line with the objective-driven approach. Thus, the candidate has a clear benchmark to judge the relative importance of each research activity, being able to avoid those which are less likely to conduct to successful and timely completion of the Ph.D.

Figure 4 shows an analysis of the number of MSc and Ph.D. theses successfully completed in the AJPU. The completion of the MSc thesis is done at a constant and relatively high pace. The completed Ph.D. theses obviously grow at a lower rate but still show a very positive trend of improvement.

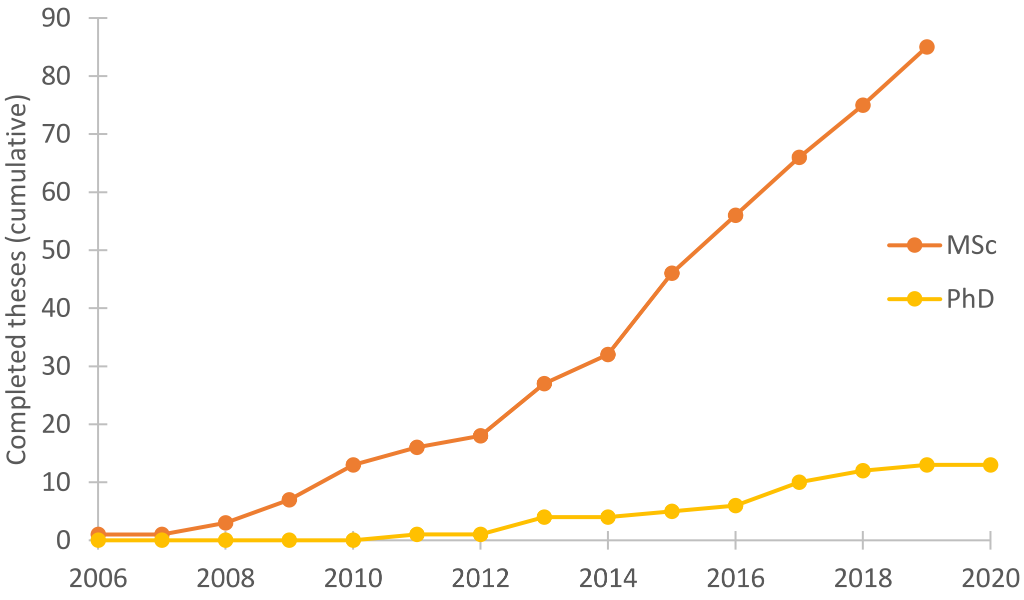

Figure 4: Evolution of completed postgraduate thesis during the period of operation of the AJPU

MSc and Ph.D. alumni from the AJPU can now be found working in diverse institutions all over the world, from research universities and institutes to research-driven firms. This is shown in Figure 5 and is perhaps the most significant proof of effective knowledge dissemination.

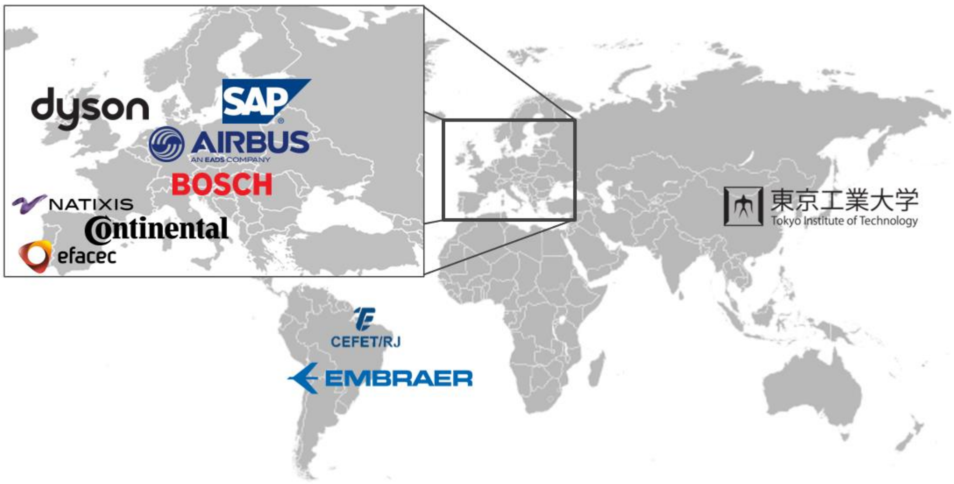

Figure 5: Work locations of AJPU alumni

3.2.3. Teaching activities

Since this research group operates within a relatively specialized subject matter within the overarching and diverse field of mechanical engineering, it is essential to ensure that the skills being transferred via teaching activities are not solely restricted to the design of structural joints. In fact, although the need for personnel skilled in implementing joining technologies is growing worldwide, given the large number of students that are part of a mechanical engineering course and its postgraduate components, many of these students will never directly have to lead with these technologies in their professional paths. The courses being taught convey not only specialized technical knowledge but must also provide the student with the necessary tools to solve related engineering problems.

The knowledge transfer process that occurs in the AJPU is carried out mainly via three different courses taught in the Department of Mechanical Engineering of FEUP. Two of these courses are taught solely at the MSc level, while another is available for both MSc and Ph.D. candidates. It should be noted that the current course organization will change in the near future with a scheduled restructuring of the mechanical engineering course contents, which will increase the time devoted to the study of joining techniques. In these courses, adhesive bonding is taught in both theoretical and laboratorial classes, where students manufacture bonded joints, test them, and execute joint strength calculations. Here, an online analytical design tool (www.jointdesigner.pt) created by the AJPU is used to help the students' design joints and understand how the different design parameters influence joint performance (da Silva, Lima, and Teixeira 2009). This deep exposure to a research procedure is not common in other courses and leads a significant number of class attendees to ingress into the MSc programmes integrated into the AJPU, as was suggested by Narayanan (1999) and Zydney et al. (2002). A special case is the Structural Adhesive Joints course, an elective course offered for Ph.D. students and MSc students alike. This course has a particular operation, as it integrates the students in current research works in the AJPU. By working closely with members of the research team, the students develop their capabilities and recognize the most important aspects associated with research into structural adhesive bonding. During the course, the student will, in fact, have the opportunity to be a *de facto* team member, participating actively in team meetings and improving his or her own knowledge by learning from a diverse set of related works, which, as Feldman, Divoll, and Rogan-Klyve (2013) suggested, is the only way to become a truly skilled and independent researcher.

3.2.4. Publication activities

The dissemination approach followed in the AJPU is to ensure that all work is of high quality and suitable posterior publication. As a result, even short research works that are carried out in the context of consulting work have carefully designed experiments.

3.2.5. Peer-reviewed journals

Publication in peer-reviewed journals is one of the most important of these activities, as it has the greatest impact on the scientific community. Work carried out in the context of master theses, Ph.D. thesis and consulting projects is almost always published in academic journals. The AJPU has published more than 437 research papers which have received almost 12.000 citations. This corresponds to a Hirsch index value of 59 (Scopus 7/11/2021). Furthermore, some of its members are editors and on the board of several highly ranked journals in the field.

3.2.6. Books

Writing and publishing reference books is also highly important to ensure effective knowledge transfer. Reference books are a powerful way to digest the knowledge that is published in scientific papers, serving as a concise and focused source of information. In addition, many of these books are used as a reference in industrial settings and have also served as a vehicle to initiate cooperation between the industry and the research group. These range in complexity, from support material to the classes that are taught on structural joining up to highly focused reference books aimed at a specific subject within the field of joining.

3.2.7. Scientific conferences

Active participation in scientific conferences is fundamental to allow a Ph.D. or MSc candidate to become truly familiarised with its research field and to experience first-hand the state-of-the-art. The group is extremely active in the organization of scientific conferences related to structural joining, material science and technological education, enabling the formation of important bridges of cooperation between researchers of different institutions and countries. The AJPU organizes the International Conference on Science and Technology Education (STE), a reflection of the effort that the AJPU has devoted to ensuring quality and effectiveness in its pedagogical activities.

3.3. Technological transfer activities

At the AJPU, technological transfer is achieved via two distinct routes. The first consists in direct industrial consulting activities, with collaborative work between the unit and industrial institutions. The second is the technical qualification of personnel, providing vocational educational training aimed at the manufacturing sector.

3.3.1. Direct industrial consulting

In our experience, dissemination is almost always the catalyst for initiating work to be carried out in cooperation with industrial partners, as R&D departments are actively searching for relevant publications in the advanced joining process field. Thus, the effectiveness of good quality, published research is very often superior to that of a direct offer of services.

Consulting activities are mostly driven by direct requests from industrial users who wish to cooperate with the unit to solve specific issues in their manufacturing or design processes. This can be achieved by different means. One of the options has already been discussed above and pertains to an academic qualification activity. This allows for a very direct and involved process, where the goals of the industrial entity and the candidate align to reach the successful completion of the thesis. For short-scale research activities, a more focused research activity is proposed. In this case, the work is distributed by the group members according to their specific skills. Lastly, it is possible to support research procedures by establishing a consortium of companies. This approach is especially suitable for cases where different companies share a common problem and are willing to cooperate with an academic partner.

In these consulting activities, the need for the establishment of clear objectives is critical. This will allow for precise management of expectations and identification of what is and what is not possible. Industrial and academic institutions should never operate under strict assumptions, which will inevitably lead to significant issues further along the project. Thus, the experience of the work carried out in consulting activities is that consistent communication is crucial. Still, the research process of an academic institution differs from those encountered within industrial research and development departments and a degree of separation must be enacted to ensure some creativity and room for error and exploration of alternatives, a process which, as de Wit-de Vries et al. (2019) explained, might be impaired by flawed communication.

3.3.2. Technical qualification

In line with its research activities, the AJPU provides vocational educational training in adhesive bonding. The European Welding Federation developed a harmonized qualification system, which divides the training process into three levels: European Adhesive Bonder (EAB), Specialist (EAS) and Engineer (EAE). Currently, in Portugal, the first level of training corresponding to the European Adhesive Bonder is already in operation (Barbosa et al. 2021), taught by the AJPU members. Another positive feedback loop has arisen from teaching these courses, as the trainees often contact the unit at a later date to establish collaborations. The AJPU also participated in the AdTech project, delivering a European qualification standard for professionals that use this technology.

4. Conclusions

In this work, an initial literature review has been made, showing that the modern engineering research group is a complex but fundamental unit in the research process. To be successful, it must operate with clear and result-oriented leadership, able to provide a work environment that has strong and well-defined goals while providing the necessary resources and the freedom to explore new concepts. Likewise, communication is an important step of the research group management process, as it allows for the group to act as a truly cooperative team, maximizing knowledge. Training of scientific personnel should be a key activity of each research group and its effectiveness is increased by fully integrating postgraduate students in all the group activities, allowing them to scrutinize and comment on all being carried out.

It is proposed that an effective operation process follows a circular process, which is initiated with the knowledge generation activities, followed by the dissemination of this knowledge and, lastly, the transfer of this knowledge or technology to industry.

Effective knowledge dissemination is also shown to be of great importance, as it exposes the group member to a constant stream of constructive criticism, positions the group members in the academic research environment and ultimately generates important consulting opportunities. The effectiveness of high-quality published research has been found to be superior to that of direct contact and offer of services to companies.

Technological transfer is found to be the most crucial step of the research cycle, being key to identifying new research paths that will have a positive impact not only on an academic level but also on society.

References

Barbosa, A. Q., L. F. M. da Silva, A. Loureiro, E. A. S. Marques, R. Carbas, and S. de Barros. 2021. "European adhesive bonder-a targeted training for portuguese professionals harmonized with European directives". *U.Porto Journal of Engineering* 7, no. 1: 37-47. https://doi.org/10.24840/2183-6493_007.001_0006.

Bercovitz, J., and M. Feldman. 2006. "Entpreprenerial universities and technology transfer: A conceptual framework for understanding knowledge-based economic development". *Journal of Technology Transfer* 31, no. 1: 175-88. https://doi.org/10.1007/s10961-005-5029-z.

Bland, C. J., and M. T. Ruffin. 1992. "Characteristics of a productive research environment: Literature Review". *Academic Medicine* 67, no. 6: 385-97. https://doi.org/10.1097/00001888-199206000-00010.

Braun, S., C. Peus, D. Frey, and K. Knipfer. 2016. "Leadership in Academia: Individual and collective approaches to the quest for creativity and innovation". In *Leadership Lessons from Compelling Contexts*, 349-65. Emerald Group Publishing Limited. https://doi.org/10.1108/S1479-357120160000008013.

D'Este, P., and M. Perkmann. 2011. "Why do academics engage with industry? The entrepreneurial university and individual motivations". *Journal of Technology Transfer* 36, no. 3: 316-39. https://doi.org/10.1007/s10961-010-9153-z.

Eekels, J., and N. F. M. Roozenburg. 1991. "A methodological comparison of the structures of scientific research and engineering design: their similarities and differences". *Design Studies* 12, no. 4: 197-203. https://doi.org/10.1016/0142-694X(91)90031-Q.

Evans, L. 2012. "Leadership for researcher development: What research leaders need to know and understand". *Educational Management Administration and Leadership* 40, no. 4: 423-35. https://doi.org/10.1177/1741143212438218.

Feldman, A., K. A. Divoll, and A. Rogan-Klyve. 2013. "Becoming researchers: The participation of undergraduate and graduate students in Scientific Research Groups". *Science Education* 97, no. 2: 218-43. https://doi.org/10.1002/sce.21051.

Feller, I., C. P. Ailes, and J. D. Roessner. 2002. "Impacts of research universities on technological innovation in industry: Evidence from engineering research centers". *Research Policy* 31, no. 3: 457-74. https://doi.org/10.1016/S0048-7333(01)00119-6.

Hackman, J. R., and Walton R. E. 1986. "Leading groups in organizations". In *Designing effective work groups*, edited by P. S. Goodman. San Francisco: Jossey-Bass.

Hansson, F., and M. Mønsted. 2008. "Research leadership as entrepreneurial organizing for research". *Higher Education* 55, no. 6: 651-70. https://doi.org/10.1007/s10734-007-9081-5.

Heinze, T., P. Shapira, J. D. Rogers, and J. M. Senker. 2009. "Organizational and institutional influences on creativity in scientific research". *Research Policy* 38, no. 4: 610-23. https://doi.org/10.1016/j.respol.2009.01.014.

Isaacson, W. 2012. "The real leadership lessons of Steve Jobs". *Harvard Business Review* 90, no. 4. https://hbr.org/2012/04/the-real-leadership-lessons-of-steve-jobs.

Latour, B. 1987. *Science in action: How to follow scientists and engineers through society*. Harvard University Press.

Melin, G. 2000. "Pragmatism and self-organization: Research collaboration on the individual level". *Research Policy* 29, no. 1: 31-40. https://doi.org/10.1016/S0048-7333(99)00031-1.

Mirowski, P., and R. Van Horn. 2005. "The contract research organization and the commercialization of scientific research". *Social Studies of Science* 35, no. 4: 503-48. https://doi.org/10.1177/0306312705052103.

de la Mothe, J. 1992. "The revision of international science indicators: The Frascati manual". *Technology in Society* 14, no. 4: 427-40. https://doi.org/10.1016/0160-791x(92)90037-b.

Narayanan, R. M. 1999. "Use of objective-based undergraduate research project experience as a graduate student recruitment tool". *Journal of Engineering Education* 88, no. 3: 361-65. https://doi.org/10.1002/j.2168-9830.1999.tb00458.x.

Plerou, V., L. A. Nunes Amaral, P. Goplkrishnan, M. Meyer, and H. E. Stanley. 1999. "Similarities between the growth dynamics of university research and of competitive economic activities". *Nature* 400, no. 6743: 433-37. https://doi.org/10.1038/22719.

Popper, K. 2014. *Conjectures and refutations: The growth of scientific knowledge*. Routledge.

Schmoch, U., and T. Schubert. 2008. "Are international co-publications an indicator for quality of scientific research?". *Scientometrics* 74, no. 3: 361-77. https://doi.org/10.1007/s11192-007-1818-5.

Sherwin, C. W., and R. S. Isenson. 1967. "Project hindsight". *Science* 156, no. 3782: 1571-77. https://doi.org/10.1126/science.156.3782.1571.

da Silva, L. F. M., R. F. T. Lima, and R. M. S. Teixeira. 2009. "Development of a computer program for the design of adhesive joints". *Journal of Adhesion* 85, no. 12: 889-918. https://doi.org/10.1080/00218460903307761.

Top, J., and J. Broekstra. 2008. "Tiffany: Sharing and managing knowledge in food science". Keynote in ISMICK-12th International Symposium on the Management of Industrial and Corporate Knowledge, Brazil, November 2008.

de Wit-de Vries, E., W. A. Dolfsma, H. J. van der Windt, and M. P. Gerkema. 2019. "Knowledge transfer in university–industry research partnerships: A review". *Journal of Technology Transfer* 44, no. 4: 1236-55. https://doi.org/10.1007/s10961-018-9660-x.

Ziman, J. M. 1987. *An introduction to Science Studies: The philosophical and social aspects of science and technology*. Cambridge University Press.

Zydney, A. L., J. S. Bennett, A. Shahid, and K. W. Bauer. 2002. "Impact of undergraduate research experience in engineering". *Journal of Engineering Education* 91, no. 2: 151-57. https://doi.org/10.1002/j.2168-9830.2002.tb00687.x.